# Signatures of the equatorial Ionosphere in kinematic positioning and gravity field recovery

**using Swarm $L3$ residuals and time derivatives of the $L4$ linear combination**

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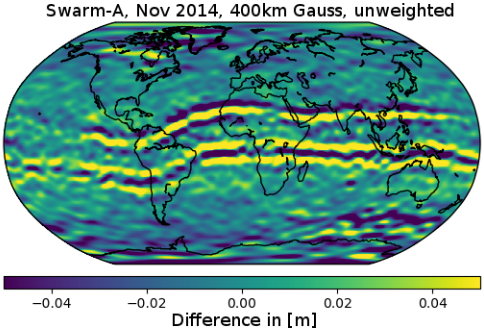
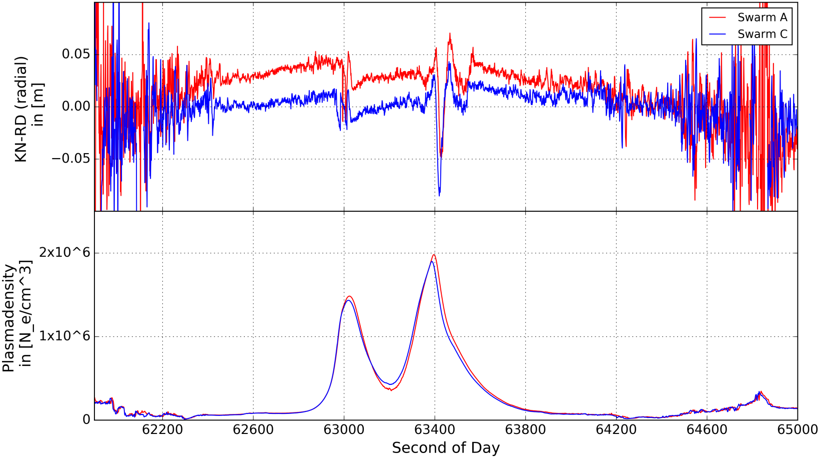
# Swarm gravity field




Geoid hight differences, static GRACE gravity field AIUB-GRACE03S - Swarm A gravity field, November 2014

# Kinematic-Reduced dynamic Orbit (radial) and Plasmadensity

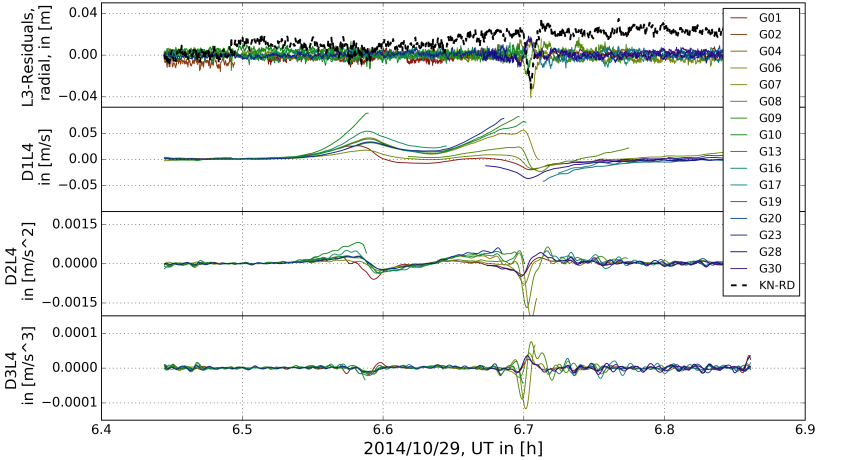


# Observation equations

$$L^i_{1k} = \rho^i_k - I^i_k(f_1) + T^i_k + c\delta_k - c\delta^i + \lambda_1 n^i_{1k}$$
$$L^i_{2k} = \rho^i_k - I^i_k(f_2) + T^i_k + c\delta_k - c\delta^i + \lambda_1 n^i_{2k}$$
$$L^i_{3k} = \frac{1}{f_1^2 - f_2^2}(f_1^2 L^i_{1k} - f_2^2 L^i_{1k}) \quad \text{:ionosphere-free linear combination}$$
$$L^i_{4k} = L^i_{1k} - L^i_{2k} \quad \text{:geometry-free linear combination}$$

$\rho^i_k$: Slant range
$I^i_k$: Ionospheric phase delay
$T^i_k$ : Tropospheric delay
$\delta_k, \delta^i$: Receiver/transmitter clock correction
$n^i_{1k}, n^i_{2k}$: ambiguities

# Time derivatives of the L4





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# The Model



- Idea: using the epoch wise variances in the derivatives to detect possible affected epochs.
- $\mathcal{V}(t)$ is the set of visible GPS satellites at epoch $t$.
- $D^i L_j$ $i$-th time derivative of linear combination $j$.
- $sd$ denotes the standard deviation.

$$
\begin{aligned}
sd_{L3}(\hat{\mathcal{V}}(t), t) = & c_0 + c_1 \cdot sd_{D^1 L_4}(\mathcal{V}(t), t) \\
& + c_2 \cdot sd_{D^2 L_4}(\mathcal{V}(t), t) + c_3 \cdot sd_{D^3 L_4}(\mathcal{V}(t), t)
\end{aligned}
$$



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# Observation specific weighting

We define an observation specific weight:

$$\omega(G_k, t) = sd_{L3}(-G_k, t)/sd_{L3}(t)$$

$G_k$: GPS-Satellite $k$

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$$\omega(G_k, t) = sd_{L3}(-G_k, t)/sd_{L3}(t)$$

$G_k$: GPS-Satellite $k$The Observation specific $\sigma$ is defined as $1/\omega$ and was scaled with a factor of $100$.

$$\sigma_{scaled} = (\sigma - 1) \cdot 100$$

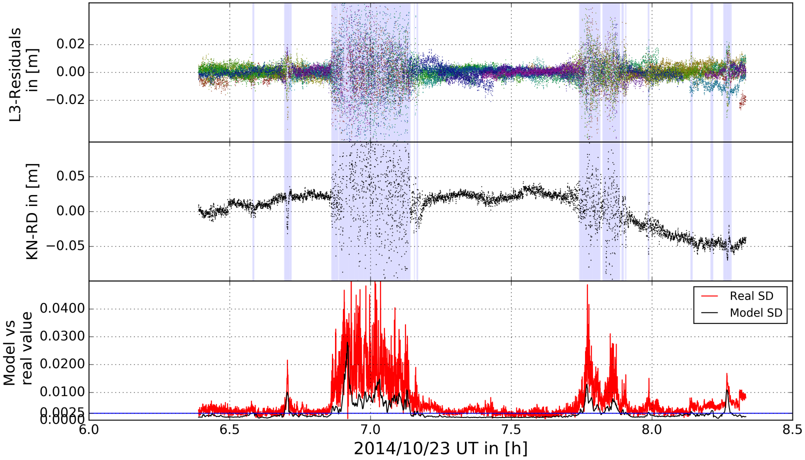
Any $\sigma < 1$ was set to $1$.

# Evaluation

Model trained individally for 30 days in Nov. 2014

| | mean | sd | min | max |
|---|---|---|---|---|
| $c_0$ | 0.00094 | 0.00009 | 0.00084 | 0.00133 |
| $c_1$ | $-0.0520$ | 0.0115 | $-0.0820$ | $-0.0300$ |
| $c_2$ | 9.4031 | 1.0230 | 7.9196 | 12.3240 |
| $c_3$ | 73.4637 | 13.1162 | 47.7995 | 108.0637 |
| correlation | 0.8249 | 0.0712 | 0.6138 | 0.8942 |

# Detection of affected epochs





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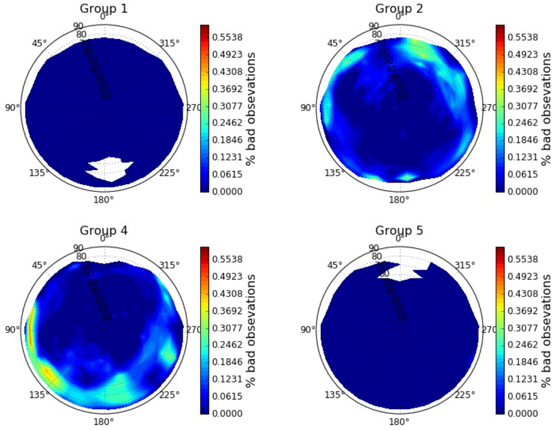
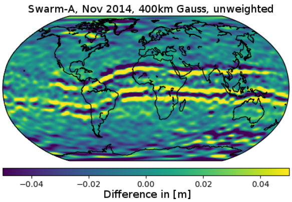
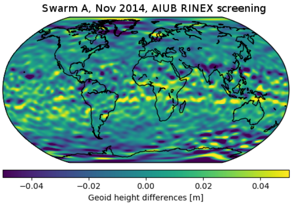
# Identification and position of affected Satellites

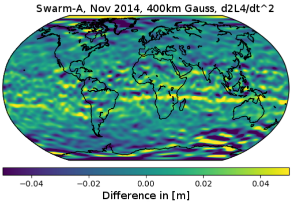


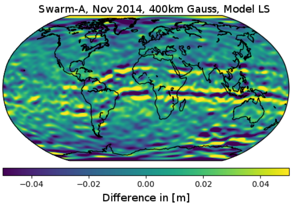

| Group | MLAT(UP) |
|---|---|
| 1 | $-35 \rightarrow -25$ |
| 2 | $-25 \rightarrow -10$ |
| 3 | $-10 \rightarrow 10$ |
| 4 | $10 \rightarrow 25$ |
| 5 | $25 \rightarrow 35$ |

# Observation specific weighting (preliminary results)



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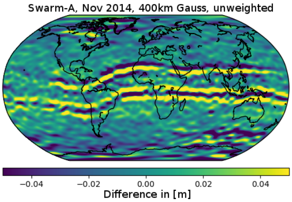
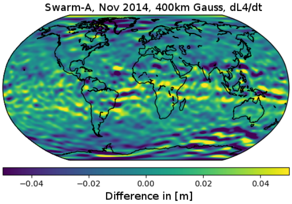
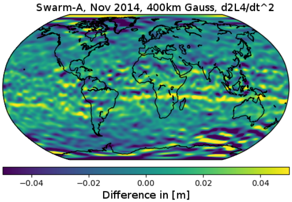
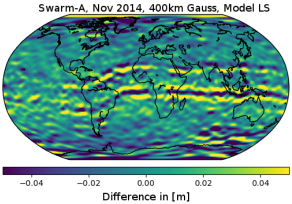


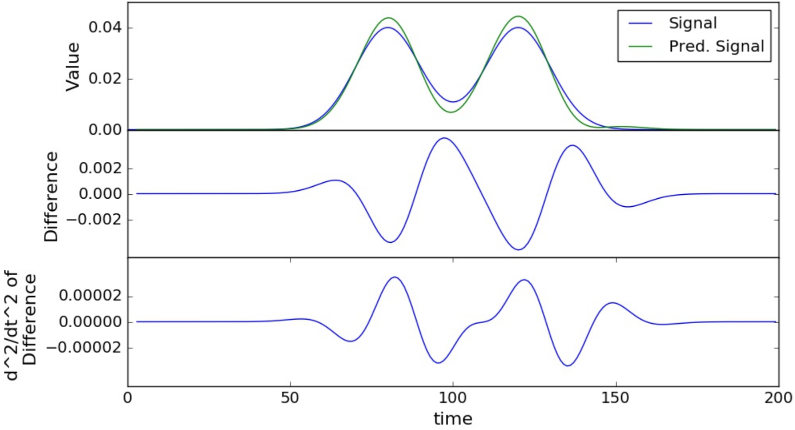



# Further tests

- Threshold for second and third derivative
- How does the receiver work? Extrapolation approach.



# Conclusions

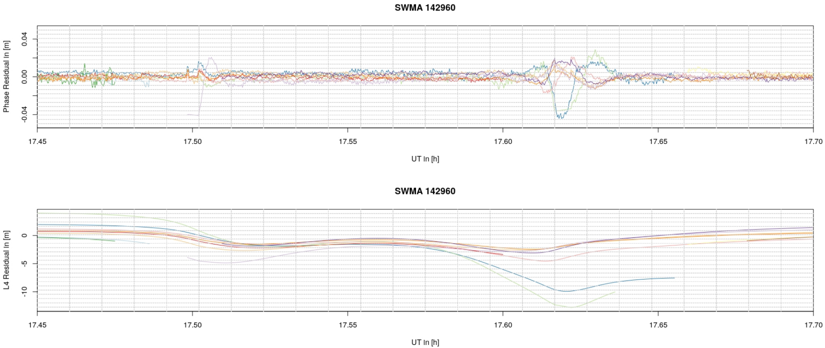
- A high variation in L4 seems to triggers artefacts in kinematic positioning.
- The standard deviation of L3 is predictable by the L4 time derivatives up to a correlation $> 0.8$.
- The second time derivative seems to be a better indicator for affected epochs than the first time derivative.

**Thank you for your attention.**

**Open for discussion.**

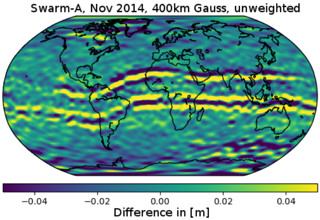
# $L3$ and $L4$ residuals

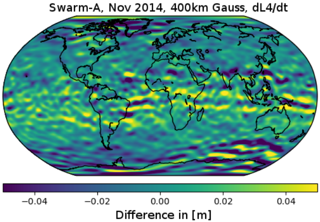


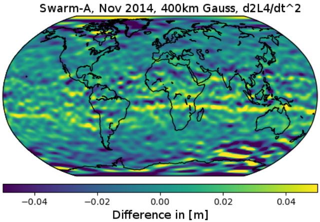


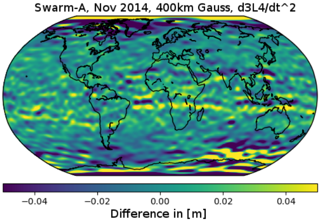

$L3$ and $L4$ residuals during an equatorial pass.

# Derivatives only



# Model evaluation